The more we do, the less we gain? Balancing effort and efficacy in managing the Solidago gigantea invasion

Dávid U. Nagy  
Pécsi Tudományegyetem

Emily S.J. Rauschert  
Cleveland State University, e.rauschert@csuohio.edu

Tamás Henn  
József Attila Library and Museum Collection

Kevin Cianfaglione  
Faculté des sciences et techniques - Université de Brest (UBO)

Szilvia Stranczinger  
Pécsi Tudományegyetem

See next page for additional authors
Follow this and additional works at: https://engagedscholarship.csuohio.edu/scibges_facpub

Part of the Biology Commons
How does access to this work benefit you? Let us know!

Recommended Citation
Nagy, Dávid U.; Rauschert, Emily S.J.; Henn, Tamás; Cianfaglione, Kevin; Stranczinger, Szilvia; and Pal, Robert W., "The more we do, the less we gain? Balancing effort and efficacy in managing the Solidago gigantea invasion" (2020). Biological, Geological, and Environmental Faculty Publications. 243. https://engagedscholarship.csuohio.edu/scibges_facpub/243

This Article is brought to you for free and open access by the Biological, Geological, and Environmental Sciences Department at EngagedScholarship@CSU. It has been accepted for inclusion in Biological, Geological, and Environmental Faculty Publications by an authorized administrator of EngagedScholarship@CSU. For more information, please contact library.es@csuohio.edu.
INTRODUCTION

Invasive plant species can be a major factor in causing biodiversity loss (Pyšek et al., 2004). Land use change and cultivation/livestock practices, together with rapid increases in population and the transportation of goods, have opened new ways of introducing organisms onto new continents. Invasive plant species are now colonising habitats independently of their natural dispersal.
abilities, signalling the start of new plant invasions. Once locally established, invaders can cause the degeneration of plant communities, landscape changes and ecosystem impacts by altering biodiversity, environmental conditions and community structures (Hejda et al., 2009). Hence, there is an increasing need for effective management, which can both suppress invaders and restore community functions (An et al., 2007).

The length of time a site is managed might be one of the most influential factors when looking at successful control methods, but, as Kettenring and Adams (2011) suggest, there is a lack of information on the long-term effects of invasive plant management, as most studies last only a few years. Short-term (up to 5 years) and long-term (more than 5 years) control techniques may have significantly different effects on the outcome of treating plant invasions. Short-term protocols create gaps in the vegetation and reduce the density of the invader; however, this does not necessarily lead to sustained changes due to the invaders’ rapid recovery after the abandonment of the treatment (Reid et al., 2009). Therefore, management and monitoring need to be long-term endeavours.

Systematic, anthropogenic disturbances create secondary communities, which are influenced by secondary successional processes. By their very nature, secondary communities are unstable and not resilient if the disturbance ceases (Nagy et al., 2016). For that reason, these communities are more vulnerable to alien species invasion (Lake and Leishman, 2004). On the other hand, invasive plant management unavoidably causes community disturbance, resulting in abiotic (mechanical, chemical) and biotic impacts to the environment. This disturbance could help to mitigate the impacts of invasion when it exclusively results in the mortality of the invader (Buckley et al., 2007). In addition, an appropriate disturbance on the compromised sites can enhance the resistance of a community against an invader (Chambers et al., 2014). However, site resistance depends on the nature and level of the disturbance and on the surviving resident native community.

Successful management should not only focus on reducing invader density, but also on preventing reinvasion by increasing the resistance of native communities. But how can the resistance of a community be estimated? Communities with high diversity are generally more resistant to invasion (Byun et al., 2013); in contrast to this, there is a positive correlation between native and invasive species richness which has been observed at larger scales (Sax, 2002). However, this can also be the result of other external factors, such as heterogeneity of resource availability at large scales (You et al., 2013). Therefore, an increase in biodiversity, combined with the reduction in number of an invading species, may increase community’s resistance and land managers should aim for this outcome.

Normally, invaded communities can be exposed to multiple types of control strategies simultaneously (e.g., grazing, mowing, herbicide spraying, manual removal). The cumulative effect of combining these regimes can increase management efficiency (Firn et al., 2015). Using more than one treatment can be a very useful tool in community conservation, particularly when used with adaptive management, especially when those management options are applied and based on pattern of and changes in the structure of a site’s vegetation (Lynn, 2013).

Solidago gigantea Aiton is a rhizomatous perennial herb native to North America. Its global distribution is circumpolar, which includes Europe and Asia. In North America, S. gigantea usually prefers wetlands, while in its invaded range, it also occupies dry habitats. Many factors play role in the invasion success of S. gigantea, such as its strong competitive ability at high abundance, which significantly decreases species richness in invaded communities (Pal et al., 2015). Typical management includes mechanical control, like grazing, mowing, ploughing and mulching. Solidago gigantea is broadly tolerant to numerous biotic and abiotic stressors (Shibel and Heard, 2016). Its rhizomes can rapidly spread and regenerate (Nagy et al., 2018), making management challenging, since rhizome fragmentation and dispersal should be avoided.

Our goal was to find an optimal balance when managing secondary grasslands, in order to maintain the highest species diversity, while reducing the Solidago gigantea invasion. We investigated the impacts of individual and combined treatments on S. gigantea and its associated communities. In addition, we compared the outcomes of short- and long-term applications. To this end, we conducted plot surveys in naturally occurring populations that had been managed by Duna-Dráva National Park in Hungary. These long-term treatments provided an opportunity for us to expand on our previous knowledge of how to control S. gigantea. The following hypotheses drove our investigations: (a) long-term (in our case more than 8 years) management decreases invader density and increases diversity more than short-term (in our case 2 years) treatments; (b) each applied management option influences the abundance of the invader differently; and (c) combining management options with mowing may have negative effects on management success.

2 | MATERIALS AND METHODS

2.1 | Short-term mowing treatment

To investigate the short-term effects of mowing, a mesic meadow containing mixed shrubs, other herbaceous species and established S. gigantea patches was selected in Pellérd, Baranya County, Hungary (Figure 1; Table 1). The area surrounding the study site was regularly used as agricultural land or for tree plantations, and, in addition, no S. gigantea management had been previously applied to this area. The study site was divided into two parts; one of which was mowed while the other part was left untreated.

The mowing treatment was applied for two years in June, which is the growing phenophase of our target species. In 1 × 1 m fixed quadrates, the treatment was conducted using a hand clipper to cut the vegetation to approximately 10-15 cm above the soil surface while leaving the hay. One year after the first treatment application, data collection was performed. Data on Solidago stem number and estimated per cent cover of all vascular plant species were collected for 2 years.
2.2 Long-term study sites

To investigate the long-term effects of the different types of commonly used management practices, we conducted observational surveys in Duna-Dráva National Park (498.78 km²), where the invasion of *S. gigantea* is considered a serious problem. In this national park, *S. gigantea* control efforts started 8–25 years ago, depending on the section of the park. We chose five study sites (Table 1) in Baranya and Somogy Counties, located in south-west Hungary, and at each site, a different treatment was used.

The minimum distance among study sites was 8.10 km, while the maximum was 92.15 km. Study site selection was based on similarity of habitat, vegetation type and applied management techniques, which will help decrease the effect of extremely different biotic and abiotic environmental factors. All study sites belong to the same climatic and floristic zone, and the soil was identified as meadow type. Soil moisture ranged between 30% and 40% during the vegetation period at each site. The vegetation cover at all sites was devoid of trees.

2.3 Long-term management techniques

2.3.1 Mowing treatment

To measure the long-term effects of mowing, a study site at Drávakereszttúr was selected and sampling occurred where mowing had been applied annually for twenty years during the growing phenophase (June) of the target species. At the study site, treated and untreated sections were separated with fences. Mowing was conducted by using a tractor-mounted grass cutter. The vegetation was cut to approximately 10–15 cm above the soil surface and without removing the hay afterwards.

2.3.2 Grazing treatments

The impact of grazing by two different types of livestock was investigated, because the grazing habit of cattle and sheep strongly differ (Putfarken et al., 2011). In general, cattle do not graze vegetation shorter than 10–15 cm above the soil surface. In contrast, sheep grazing is more intense, since they chew the vegetation down to 0–5 cm above the soil surface, regularly creating bare ground.

Near Irmapuszta, long-term cattle grazing was applied as a management option for over ten years. At the study site, an untreated area was selected and then separated by fencing to protect it from grazing. Cattle grazed on this land from April to November. The stocking density of cattle was 8 animals/ha.

For 13 years, long-term sheep grazing was applied as a management option in the vicinity of Darány. At this study site, the untreated area was separated by fencing to protect it from grazing by sheep. The sheep grazed throughout the area from May to mid-October. The stocking density for sheep was 10 animals/ha.

2.3.3 Cattle grazing with mowing treatment

Cattle grazing has a less intense impact on plant communities than sheep grazing, which allows land managers to combine cattle
NAGY et al.

2.3.1 Grazing options

In Marcali, cattle grazing was combined with mowing for ten years. In the study site, an untreated area was separated by fencing to protect it from grazing. Cattle were grazed throughout the area from April to November. The stocking density for cattle was 8 animals/ha. To prevent shrub growth, mowing happened once a year on the study site between April and June. Mowing was conducted using a tractor-mounted grass cutter. Vegetation was cut to approximately 10–15 cm above soil surface without removing the hay afterwards.

2.3.2 Flooding treatments

Three flooding regimes were carried out at the same study site, Csomárd, for six years. The study site was designed in the meadows around an artificial lake. A part of the meadow was periodically flooded while the control area was separated by a 3 m tall and 4 m wide embankment that would allow it to be left untreated. Water levels were artificially controlled, and flooding occurred when water levels reached 10-15 cm above the soil surface for one month (from late spring to early summer). For the rest of the year, water saturation of the soil was controlled to sustain the moisture status needed (40%–50%) for species of conservation interest (Dactylorhiza incarnata and Menyanthes trifoliata). The flooding treatments were combined with different intensities of mowing: flooding without mowing, flooding with mowing once a year (June) and flooding with mowing twice a year (June and August) (the flowering phenophase of the species). Mowing was conducted by using a tractor-mounted grass cutter. Vegetation was cut to approximately 10.15 cm above soil surface without removing the hay afterwards.

2.4 Data collection and statistical analyses

Data collection was carried out during the shoot growing phase of S. gigantea (around June, before any management options) in 2013 in long-term and in 2013-2014 in short-term study sites. The 1 x 1 m plots were placed randomly at each site: 50 in the treated and 50 in the untreated (control) areas. The following data were recorded for each plot: vascular plant species, the estimated percent cover of vascular plants and the number of S. gigantea stems.

Statistical analyses were performed in R, version 3.5.3 (R Development Core Team, 2019). The response variables were the density of S. gigantea, the species richness and Shannon diversity in plots and the percent cover of vascular plants and the number of S. gigantea stems. Statistical analyses were performed using linear model including two fixed factors: management (managed and unmanaged plots) and year (first and second year). In the model, year was treated as a repeated measure. F tests were used for unmanaged plots) and year (first and second year). In the model, year was treated as a repeated measure. F tests were used for

TABLE 1 Details of study site characteristics and treatments

<table>
<thead>
<tr>
<th>Study type</th>
<th>Study site</th>
<th>Unmanaged area (km²)</th>
<th>Managed area (km²)</th>
<th>Lat/Long</th>
<th>Mean annual temperature (°C)</th>
<th>Mean annual precipitation (mm)</th>
<th>Treatment</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-term</td>
<td>Pellérd</td>
<td>15.3</td>
<td>32.8b</td>
<td>46.03172; 18.138722</td>
<td>11.1</td>
<td>655</td>
<td>Mowing once a year</td>
<td>2 years</td>
</tr>
<tr>
<td>Long-term</td>
<td>Drávakeresztúr</td>
<td>7.6</td>
<td>16.7</td>
<td>45.823224; 17.755449</td>
<td>11.2</td>
<td>719</td>
<td>M: Mowing once a year</td>
<td>20 years</td>
</tr>
<tr>
<td></td>
<td>Irmapuszta</td>
<td>7.5a</td>
<td>24.0</td>
<td>45.8980194; 17.7935972</td>
<td>10.9</td>
<td>636</td>
<td>C: Grazing by cattle</td>
<td>10-15 years</td>
</tr>
<tr>
<td></td>
<td>Darány</td>
<td>11.99</td>
<td>27.9</td>
<td>45.967436; 17.5959104</td>
<td>10.8</td>
<td>720</td>
<td>S: Grazing by sheep</td>
<td>13 years</td>
</tr>
<tr>
<td></td>
<td>Marcali</td>
<td>8.3a</td>
<td>35.3</td>
<td>45.590234; 17.440110</td>
<td>10.8</td>
<td>652</td>
<td>CM: Grazing by cattle and mowing</td>
<td>10 years</td>
</tr>
<tr>
<td></td>
<td>Csomárd</td>
<td>27.8</td>
<td>87; 93; 76</td>
<td>46.447637; 17.659344</td>
<td>10.7</td>
<td>661</td>
<td>F: Flooding; FM: Flooding + mowing once a year</td>
<td>6 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FMM: Flooding + mowing two times a year</td>
<td></td>
</tr>
</tbody>
</table>

Note: Managed and unmanaged areas are continuous areas of land at the study sites, unless otherwise stated as 10 × 100-m² quadrats or 100 × 1-m² quadrats.
statistical hypothesis testing. For pair-wise comparisons, Tukey’s post hoc tests were conducted to compare each management/year combinations.

Each long-term option, except flooding regimes, was analysed with two sample t tests, where managed plots were compared to unmanaged plots from the same study site. Flooding regime had four levels (control, flooded, flooded plus mowing once and flooded plus mowing twice); therefore, a linear model with one fixed factor (applied management) was used to test the effect of different management options on the measured variables. F tests were used for statistical hypothesis testing. For pair-wise comparisons, Tukey’s post hoc tests were conducted to compare each management/year combinations.

3 | RESULTS

3.1 | Duration of management

Short-term mowing significantly decreased (df = 1; $F = 175.87; \ p < .001$) the invasive species’ density in the first year by 81.2% (30 fewer stems; $t = -9.618; \ p < .05$) and at the second year by 72.6% (28.5 fewer stems; $t = -9.137; \ p < .001$) compared to each year’s controls (Figure 2). In contrast, short-term mowing did not influence species richness (df = 1; $F = 0.240; \ p = .633$; Figure 3), nor Shannon diversity (df = 1; $F = 0.044; \ p = .836$; Figure 4) of the plots. However, there was a species shift between treated plots; the frequency of Arrenatherum elatius, Dactylis glomerata, Gallium mollugo and Vicia hirsuta decreased and frequency of Calamagrostis epigeios, Erigeron annuus, Medicago lupulina, Picris hieracioides, Taraxacum officinale and Vicia angustifolia increased. There was no difference between the first or second year controls in any of the measured parameters.

In contrast to short-term mowing, every long-term management options led to a significant reduction in $S. gigantea$ performance and an increase in species richness and community diversity compared to its own control (Figures 2, 3 and 4). In the grazed and mowed sites, frequency of Achillea collina, Erigeron annuus, Festuca pratensis, Picris hieracioides and Poa pratensis increased, while at the flooded site, the frequency of Equisetum palustre, Eupatorium cannabinum, Mentha aquatica and Polygonum mite increased.

3.2 | Differences among long-term management options

In all management treatments, there was a significant negative effect on $S. gigantea$ stem number (Figure 2). Long-term mowing had the least strong, but still significant, effect on stem number, decreasing it...
by 42.0% compared to its own control (22.5 fewer stems; t = -3.414; p < .01). Flooding with mowing twice a year decreased stem density by 60.8% (17.9 fewer stems; t = -15.797; p < .001), flooding with a single mowing decreased it by 83.0% (24.45 fewer stems; t = -21.172; p < .001), and cattle grazing combined with mowing decreased stem number by 87.1% (33.6 fewer stems; t = -15.190; p < .001). The three most effective treatments were grazing by cattle (96.5% decrease; 41.76 fewer stems; t = -14.812; p < .001), flooding (96.9% decrease; 28.55 fewer stems; t = -25.184; p < .001) and grazing by sheep (99.8% decrease; 30.9 fewer stems; t = -11.073; p < .001).

All long-term management options increased average species richness in the treated plots (Figure 3). Compared to each treatment’s control, the least effective treatment was flooding with mowing twice, which still almost doubled species richness (3.00 more species; t = 6.274; p < .001), while the most effective treatment was flooding with a single mowing, which more than tripled the species richness (8.6 more species; t = 19.219; p < .001). Grazing by cattle resulted in the highest species richness (mean = 19.25) among all experimental sites and was almost three times higher (12.65 more species; t = 14.175; p < .001) than its control plots. Grazing by sheep also doubled the number of species present (4.85 more species; t = 14.175; p < .001). In addition, species richness in the long-term mowing site was also higher than in its control plots (7.10 more species; t = 6.892 p < .001).

Shannon diversity was increased significantly by all management options (Figure 4). Compared to its control, the least effective options were flooding with mowing twice, which increased Shannon diversity by 97.3% (0.57 more; t = 8.807; p < .001) and grazing by sheep, which increased it by 102.9% (0.70 more; t = 5.834; p < .001). Grazing by cattle led to the largest increase in Shannon diversity (1.99 more; t = 23.928 p < 0.001), raising diversity sixfold and resulting in the highest diversity (2.38) among all treatments. Long-term mowing also increased diversity by almost four times (1.02 more; t = 8.778; p < .001), compared to its control. Flooding without mowing increased diversity by almost three times (1.06 more; t = 16.283; p < .001) and flooding with single mowing increased it by more than three times (1.46 more; t = 22.442; p < .001), compared to its control.

3.3 Effects of additional mowing on management outcome

As stated above, long-term mowing by itself was the least effective treatment against the invader (Figure 2). Combining any other management option with mowing did not improve the outcome; in fact, additional mowing, in some cases, did not lead to a greater decrease in S. gigantea stem density. When grazing by cattle or flooding was combined with a single mowing, their impact on the invader’s density was statistically similar to the options without mowing. Flooding combined with mowing twice was less effective at lowering S. gigantea density (mean = 11.55), when compared to flooded plots without any mowing (10.65 more stems; t = -9.394, p < .001) or flooded plots with a single mowing (6.55 more stems; t = -5.777, p < .001).

In terms of community impacts, long-term mowing by itself had an intermediate effect when compared to other management options (Figures 3 and 4). It was found that combining cattle grazing with single mowing was less effective than cattle grazing by itself, both in species richness (7.25 less species in the grazed plus mowed site) and Shannon diversity (0.49 less in the grazed plus mowed site). In contrast to grazing, combining flooding with a single mowing had positive effect on species richness (4.15 more species; t = 9.273; p < .001) and diversity (0.4 more; t = 6.163; p < .001) when compared to plots that had flooding without any mowing. However, when mowing was applied twice, its efficacy decreased for Shannon diversity (0.49 less; t = -7.468, p < .001) when compared to the flooded plots that had no mowing; however, species richness (t = -3.239, p = .109) did not decrease in either treatment.

4 Discussion

4.1 Duration of management

This research adds important insights regarding the impacts of short- and long-term management on invader density and community diversity. It is important to mention that the short- and long-term treatments were not performed at the same site, which makes them difficult to compare due to the potential differences in several abiotic and biotic conditions or in land use history. To reduce the potential differences, we selected a site with a similar species pool in both the short-term mowing study and the long-term mowing study; in addition, the same intense mowing treatment (cut to 10-15 cm height) was used at each site.

We found that short-term mowing treatments had significant negative impacts on invader density; however, it did not positively influence native species presence and diversity. The short-term treatments decreased the frequency of large perennials (like Arrhenatherum elatius) and increased the frequency of annuals (like Medicago lupulina or Picris hieracioides), often observed in the early stages of succession. The same tendency was found under long-term mowing and grazing management: the dominance of short annuals and an increase in vegetatively spreading species when compared to the controls, which was also observed by Sendžikaitė et al. (2013). Other findings concluded that short-term mowing treatments were more effective at reducing the stem density of the invader than with long-term mowing as a management tool. This may be due to a rapid response to the newly appearing disturbance (Tilman and Lehman, 2001) whose effects ease over time by accommodation and the slow recovery of the invader.

In addition, our results showed that only long-term management options had significant positive impacts on communities, indicating that time is one of the most important factors in invasion management. This is due to the sum effect caused by continuous management as Cox et al. (2007) also suggested. In contrast, short-term
management options do not have enough time to cause structural changes beyond its effect on the invader, as was also demonstrated by Van Dyke et al. (2004). Therefore, while a decrease in the invader's density can appear rapidly following management, to achieve long-term, sustainable changes in community diversity, we cannot be content with early success.

Moreover, it is also widely recognised that invasive species exert negative impacts on communities that can persist for long periods of time (Green et al., 2011). These impacts may help individuals of the targeted invasive species or another weed species to recover after partial control (Simberloff and Von Holle, 2000). Thus, short-term control strategies often do not result in the expected long-term outcomes (Reid et al., 2009). The reason for this ineffectiveness can be a lack of native species recovery after the abandonment of weed control (Kettenring and Adams, 2011), while our results indicate that restoring the natural resistance of communities appears more often under long-term management strategies.

4.2 Intensity of management

Not only time, but also method of control has a strong impact on management outcomes. Different weed control options were examined, because they created different types of disturbances and those disturbances then influenced the effectiveness of each management type. Our experiments revealed that certain treatments were more effective than others, and this effectiveness can be related to the intensity of the disturbance created by that control option. In the context of invasion, disturbance can alter community structure and at the same time weaken the status of an invader, which promotes later successional development (Catford et al., 2012). The intermediate disturbance hypothesis (IDH) states that species diversity is maximised when the affecting disturbance(s) on a community are intermediate in frequency, intensity or extent (Sheil and Burslem, 2013). Several of the management treatments could be considered intermediate, either in intensity or frequency (such as mowing, grazing by cattle, flooding, and flooding plus single mowing). These control strategies, alone or together, constitute more of a disturbance than no management, but are not considered as intense as other treatments, and these intermediate disturbance treatments somewhat reduced S. gigantea performance while increasing diversity. This community recovery took place even though the management regimes did not involve directly augmenting the native plant community.

The most intensive methods, such as sheep grazing, grazing by cattle with mowing once and flooding with mowing twice, strongly decreased the abundance of the invasive species but had the smallest positive influence on diversity in these communities. In addition, annuals (Conyza canadensis, Scleranthus annuus, Vulpia myuros) and/or disturbance tolerant species (Eupatorium cannabinum, Lythrum salicaria, Rumex acetosella) increased their frequencies at these sites, indicating that these treatments have a strong impact on the composition of plant communities. Similar results have been reported in other studies, such as Lemmon et al. (2016), who investigated the influence of intensive sheep grazing on Lespedeza cuneate, and Pollock et al. (1998), whose experiment looked at the effects of different flooding regimes on species diversity.

In contrast to our findings, Tanentzap et al. (2014) emphasised the importance of intensive disturbance regimes over intermediate ones in reducing invasion; we argue that the failure to substantially increase diversity and the associated increased potential for facilitating secondary invasion may outweigh the benefits gained by dramatically reducing the invaders' abundance. In contrast to intensive treatments, management types with intermediate intensity have balanced effects: they decrease the invader’s fitness, while potentially increasing the diversity of communities, which can be more effective for further sustainability in the invaded communities.

4.3 Effects of combining management with mowing

In our experiment, we tested how different management options affect outcomes when each investigated management option was combined with mowing. In agreement with Firn et al. (2015), it was found that, under certain circumstances, combing multiple management options can improve the results over a single method of weed control. A single mowing enhanced the effect of flooding on species richness and diversity without decreasing its effect on the invader. In contrast, mowing twice negatively influenced the effect of flooding on the invasive species’ abundance, as well as on native diversity. In addition, a single mowing decreased the beneficial impacts of cattle grazing on both the invader and the associated plant community. There may also be an interaction between the form of the primary disturbance and additional mowing. Mowing was not a good supplement to grazing, since they both aim to reduce plant biomass directly. Because the flooding utilises a different mechanism (i.e., making environmental conditions less favourable for growth by increasing the water level), mowing can be an effective supplement if it happens once, but mowing twice appears to be less effective. This indicates that too many additional mowing events decrease the benefits of control, because those multiple events may exceed the disturbance tolerance of the community. Therefore, we recommend a combination of management options, each acting via a different mechanism, which can result in cumulative positive effects on the resident plant community when not too intensely applied.

4.4 Suggestions for practice

We found that even a short-term (2 year) mowing treatment can significantly decrease density of S. gigantea, but that it could not
improve species richness and community diversity as successfully as a long-term (20 year) mowing treatment. Therefore, to retain the natural resistance in communities, a long-term approach is needed. In contrast, the efficacy of the long-term treatment on the invader was weaker than in the short-term experiment, which could be explained by the adaptation of the invader, the site-specific factors or the absence of hay removal. Hay removal in long-term management could accelerate restoration of invaded communities. Moreover, as Świerszcz et al. (2017) found, transferring fresh hay from similar, uninvaded communities could improve restoration even in the short-term S. gigantea management plan. In addition, as Szépligeti et al. (2017) presented, timing is also an important factor in managing Solidago invasions. Their results show that mowing twice in the growing (June) and flowering phenophase (September) can have a stronger impact on the species than single mowing options. Therefore, adding mowing in September could potentially decrease the invader’s density by more than what occurred in our treatments.

Flooding is a feasible option against S. gigantea, due to its strong effect on Solidago density. Furthermore, it has a significant conservation and biological role, as flooding maintains soil moisture, provides adequate water supply to wet grasslands or marshy meadows and helps to preserve species of conservation interest (our case Dactylorhiza incarnata and Menyanthes trifoliata). This was also observed by Cservenka et al., (2017) in their control experiment against S. gigantea in Balaton-felvidéki National Park. Therefore, flooding is a useful tool to preserve diversity and, at the same time, control Solidago. In addition, combining flooding with a single mowing could increase management effectiveness by restoring community function, due to the different modes of action in these two techniques. However, when flooding was combined with two mowing treatments, it worsened the efficiency of flooding, unlike in the above-mentioned study (Szépligeti et al., 2017), indicating the combination of flooding with mowing twice is a less feasible option than flooding or flooding combined with mowing once a year.

Among the treatments we examined, long-term grazing by cattle proved to be the most effective, which strongly decreased S. gigantea density (from 43.3 to 1.5 stem/m²) and significantly increased species richness and diversity (up to 19.25 species/m² and Shannon diversity to 2.38). Moreover, cattle grazing had a more positive effect on native plant community survival than sheep grazing. Therefore, this application could be the most sustainable option in places where control by livestock is feasible. In contrast, when cattle grazing was combined with single mowing, mowing decreased the efficacy of grazing, indicating that grazing should not to be combined with mowing.

5 | CONCLUSIONS

This study investigated how a variety of commonly used control options affect the success of S. gigantea management. Our study demonstrated that management strategies, depending on the duration, disturbance type and intensity they involve, may positively or negatively influence community diversity. Intense or combined treatments with similar disturbance regimes sometimes do not result in desired outcomes; hence, intermediate and carefully combined options can lead to better success. Moreover, management maintained over a longer time period can increase the positive effects, particularly for community diversity. It is important to clarify what the goal of management is: according to our research, some treatments are only effective against the invader, but are less effective in the restoration of biodiversity. Long-term methods should not only reduce the abundance of the invader, but also enhance a community’s own resistance which will repel further invasions. Therefore, it is essential to consider multiple factors when planning sustainable management plans.

ACKNOWLEDGEMENTS

The project has been supported by the European Union, co-financed by the European Social Fund Grant no.: EFOP-3.6.1-16-2016-00004 entitled by Comprehensive Development for Implementing Smart Specialization Strategies at the University of Pécs. The project was also funded by the People Programme (Marie Curie Actions) of the European Union’s Seventh Framework Programme (FP7/2007-2013) under REA grant agreement number 300639 (R.W.P.). E.R acknowledges support from a Fulbright Scholar grant. D.U.N. acknowledges support from TÁMOP-4.2.2.B-15/KONV-2015-0011. The staff of the Duna-Dráva National Park in Hungary (Andráss Márkus, Sándor Csór, Tamás Nyemcsók, Zoltán Szegvári and László Wágner) was very helpful by introducing us to their control methods and providing site access. We thank Judit Nyulasí for her help in performing the field surveys. We are also grateful to Krystal Weilage for the linguistic polishing of our manuscript.

CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors. The submission for publication has been approved by all relevant authors. All persons entitled to authorship have been so named, and all authors have seen and agreed to the submitted version of the manuscript.

ORCID

Dávid U. Nagy  https://orcid.org/0000-0001-7742-4459
Tamás Henn  https://orcid.org/0000-0003-1679-1815
Kevin Gianfaglione  https://orcid.org/0000-0002-1336-1468

REFERENCES


How to cite this article: Nagy DU, Rauschert ESJ, Henn T, Cianfaglione K, Stranzcinger S & Pal RW. The more we do, the less we gain? Balancing effort and efficacy in managing the *Solidago gigantea* invasion. *Weed Research*. 2020;60:232–240. https://doi.org/10.1111/wre.12417